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Do Electromagnetic Pulses Induce the Relaxation or Activation of Microcracking Rate in Loaded Rocks?

/acoustic emission based study/

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Abstract. The work is devoted to the problem of role of ambient factors (external electromagnetic field, in particular) in the process of ageing of mechanically burden nonmetallic solids (rocks). A specific research point is the effect of temporary activation of Acoustic Emission (AE) of rocks specimens during action of EM field pulses applied externally. Extended experimental studies of responses of AE have been conducted to evince the changes in defects accumulation process in loaded specimens due to external power impacts (EPI). The experiments have been held on noiseless rheological machines available at Bishkek Geodynamic Research Center - RS RAS. We have tested a number of specimens made of different materials and analyzed the temporal dependence of AE activity during exposure in electric field and crossed electric and magnetic fields; the compressive load being constant. The effect of AE stimulation by power pulses (triggering) has been verified. The obtained results allow to distinguish two kinds of AE activation. The first kind involves simultaneous well correlated growth of numbers of minor and major AEs (so-called self-consistency of temporal plots of activity of different range acoustic events). The second kind represents dissimilar variations: the increment of activity of minor energy AEs, but the decrement of those of major energy. The first kind of solids material responses to EPI is prevailing when the compressive loads is under 0,85 of fracturing value. The episodes of dissimilar AE responses may signify that electromagnetic control of defects accumulation process inside rocks is possible, in principle.

Introduction

It is well-known that strong enough electric and magnetic fields have an influence on plastic straining of nonmetallic solids (particularly on the plasticity of alkali-halogenic crystals, [1 - 4]). According to these and other works some increment of plasticity occurs when the strength of electric field, E, is of order of 10 - 100 kV/m (at least, [1, 3]), or when the magnetic inductance, B, exceeds 0.1 T [4]. One can assume that electromagnetic (EM) field of such minor values of E or B components may contribute to inelastic straining (microfracture) which are evolving on micro- and meso-scales of length. Acoustic Emission (AE) is a good indicator of inelastic straining processes and microfracture inside specimens of semi-brittle materials loaded up to near critical point [5, 6]. AE method allows detection of any (even very weak) change in straining/microcracking rate in solids made of semi-brittle materials. So, temporal variations of AE activity may be considered as signatures of effects of physical fields applied externally and induced (or triggered) changes in a rate of accumulation of structural defects, microcracks in particular.

Actually, numerous experiments with pristine rocks samples and artificial solids (such as concretes and water-containing ceramics, to simulate terrestrial materials) subjected to compressive load and to additional action of EM field *have revealed AE activation as a response to external power impacts* (EPI), [7 - 9]. Our previous works [9 - 11] specified that the increment of AE activity due to EM field pulses occurs providing that the fixed compressive load over tested rock specimen is from 0.75 to 0.95 of maximal value (fracture of given specimen). We tested a number of specimens, made of materials with different elastic and piezoelectric properties: granodiorite, quartzite, granite, halite, and zirconium oxide ceramic. We argued that the effect of AEs electrostimulation is related to anelasticity of terrestrial materials under stressed-strained conditions corresponding to dilatancy rather than to structural defects clustering or formation of main crack. But the physical mechanism of electromagnetic influence is not clear completely. The excitation of microvibrations and acoustic waves during EPI is the most serious candidate to explain the responses of AE, since the effect of vibrations (even very small) on microcrack growth has been already proved [9]. It should be noted that piezoelectric effect can not be responsible for this electric to acoustic transformation because the values of piezoelectric modulus of rocks studied in [7 - 11] are too low.

An idea of F. Freund [12] that overstress before break can generate electric currents in some igneous rocks, which normally are good insulators, may be used as a starting point for more realistic approach to EM field effect over stressed-strained rocks. Shortly, F. Freund has deduced in [12] that rocks may become “p-type” semiconductors. This means that they contain mobile positive charges which can conduct some electrical charge. The crystals within such rock of abyssal origin contain some paired oxygen atoms, called peroxy groups, which can snap under stress. F. Freund speculates that once a peroxy group is snapped, a negative oxygen ion will remain trapped in the lattice of the rock, while a positive charge – or hole – will be free to flow outwards. He has proposed the model of charge transfer to natural geologic media (Earth crust) as well as to tested rock specimens [12]. Surprisingly, this model also involves such aspect as possible mechanism of interaction, of free carriers of electric charge, with an EM field externally applied to a tested rock. *The density of released positive charges should oscillate due to EM field pulses*. The oscillation of charge carriers will be delivered to the main frame of the loaded body (i.e. to the crystal lattice in the simplest case). The triggering effect of the vibrations is well-known, including the case of very weak vibrations whose amplitude of oscillating pressure is close to 10^{-6} of main compression stress [6]. The aforementioned interaction of the EM field with charges generated according to [12] is therefore a hypothesis for mechanism of electromagnetic triggering effect.

Alternative approach concerns only wetted heterogeneous rocks containing bound water or free water or its vapor in cracks and porous cavities. Authors of [13] appealed to electrokinetical phenomena in systems with solid and liquid phases. They remarked that numerous phase contacts inside heterogeneous material may be equivalent to a media with anomalous averaged polarization; the dispersion of dielectric permittivity being strong. Simplifying the consideration of [13], one can draw an analogy between vibrations occurrence in such media under electromagnetic pulses and oscillation of dielectric liquid near edge of plane capacitor biased by high frequency alternative voltage (alternative ponderomotive force acting along the gradient of electric strength will result in liquid sucking up pulsation). Similar simplified picture was sketched by T. Chelidze [14, 15] who studied the effect of EM field on slippage of contacting blocks.

No proposed model is able to evince the aspect as follows - do defects of minor or major size mostly contribute to AE activity increment under electromagnetic action? Meanwhile this issue is of great significance from viewpoint of geophysical and seismological applications of noted above effect of microcracking stimulation by EPI. The problem of the most relevance is that how to estimate a hazard of seismicity induced by man-made factors without sufficient knowledge of physics of earthquakes nucleation or reliable algorithms to predict natural events. One can regard the acoustic emission as a model of real seismisity due to well-known self-similarity property of which in a wide range of scales [6, 8, 9, 16]. Extra argumentation for the validity of such modeling is that the materials of the tested specimens are the same as for embedded rock massifs and that the typical value of compression stress during creep tests on press is close to those at depths of shallow earthquakes source-sites (5 - 15 km).

Motivated partially by above we developed investigations of AEs of rock specimens which being tested by constant uniaxial compression (so called creep test) and additional action of EM pulses. A new set of experiments under axial loading using the spring rheological press with the strength up to 100 tons was carried out. Some experiments were conducted with the help of lever loading machine

UDI-L providing compressive load up to 35 tons. The aim was to study AE in rocks specimens influenced by pulses of EM fields with parameters never been used before. Also we compared the parameters of AE responses to external impacts with that caused by trial stepwise increment of compressive load. The main results have been described below.

Experimental set-up and procedure

The work on electromagnetic- acoustic effects mentioned above involves the creep test of specimens of rocks and of artificial heterogeneous materials burden by uniaxial compression. The Fig.1 shows the rheological machines used to test rocks in noiseless conditions. We have described in details in our previous works [9, 11] the technique of long- term experiments on spring rheological press UDI (designed by A. Stavrogin, [17]) with application of external power actions. Recently, we have constructed lever machine UDI-L of 35 tons on the base of load-carrying components of UDI press. Both: spring and lever machines have been used to test solids in noiseless conditions in relevance to the problem of EM fields influence. Fig.1 shows both rheological machines. It is worth to emphasize that a lever press provides noiseless conditions at all the time of the test, including sessions of fixed compressive loads and load increments by making up the weight on a longer side of the lever. This allows continuous AE recording during stepwise change in main load, meanwhile a spring press is actually noiseless only during constant loads sessions, after clamping the displacement of compressed working spring by a screw and nuts. Besides, we remark that the effects of weak external factors cannot be studied on a usual hydraulic press because its drive produces a host of noise inevitably.

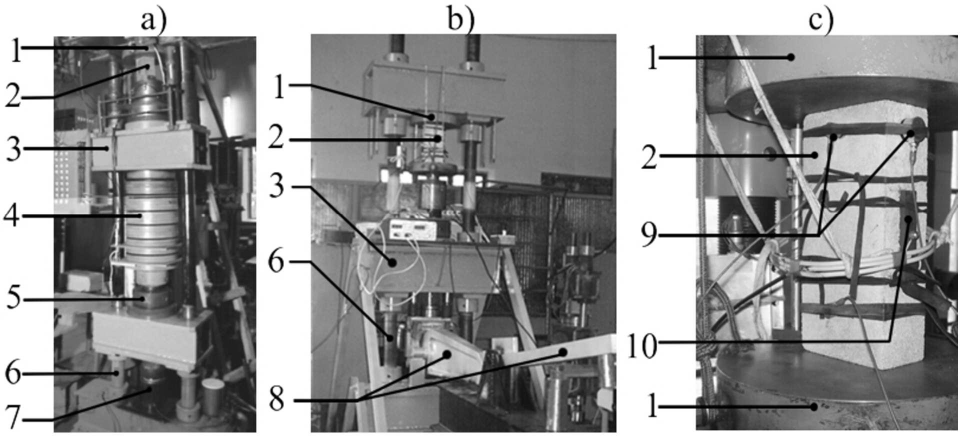

Fig.1. General views on: a) spring press UDI, b) lever machine UDI-L, c) specimen installed for tests. Denoted elements: 1- loading platen, 2 – specimen, 3 – cross-arm, 4- spring, 5- clumping nut, 6- supporting rod, 7- hydraulic jack, 8- lever units, 9 – AE sensors, 10- electrode.

Using the merits of lever and spring presses we tested rocks specimen and recorded the variations of AE signals flow during trial increment of compressive load as well as during the sessions with action of electromagnetic pulses applied externally. During last series experiments we tested 5 intact samples (granodiorite-1, granite-2, gabbro-1, and rock salt- 1) with the help of lever machine UDI-L. The total number of specimens tested on spring press with additional action of EM field was 38 (26 of them are pristine rocks).

Tested specimen was located on the lower platen with built-in AE sensors integrated constructively with cable amplifiers. The spherical joint, integrated with lower platen, assures the parallel alignment of specimen and compression axis. In most cases, single noise-immune sensors were used for recording flow of AE signals. These sensors applied to the side surface of specimen. Signals from the one of the side sensors (SE2MEG, DECI Inc.) after amplification and filtration were used to perform the triggering of recording equipment – ADC (CAMAC standard). AE signals were recorded on wide frequency region 80 kHZ - 2 MHz. This allowed signals waveform control. The measuring system operated in a waiting mode. This means that the recording starts every time when the signal magnitude exceeds threshold. Inherent noise of AE channel set a value of threshold. The value of threshold was equal nearly 1.5 times more than root-mean-square of the noise to avoid a false triggering.

Additional electric power impacts, produced by external sources, took place during a deformation session with constant level of compressive load. It took place in some time of sample exposure just after load increment but before measuring session to avoid the bias of unsteady processes caused by non-uniformity of load ramping up and edge effects (surface microchipping etc.) Permanent registration of AE started when the manifestations of transition processes (low frequency fluctuations) became of order of natural noise.

During experiments the following sources of additional power action were used: square-wave generator G5-54 giving square-wave pulses, whose amplitude was close to 50 V and duration was of order of 5 - 50 μs; the frequency varied from 1 to 50 kHz. The capacitor discharges, that supplied electric pulses, had the following parameters: time of voltage ramp about 1 μs and peak voltage of order of 1 kV. Other sources were used to reveal the significance of such factors as voltage amplitude, rate of pulse rise, and pulses repetition rate for AE activation considered. Also, we performed AE measurements during trial session with crossed electric and magnetic fields impacts. A magnetic coil supplied by AC sinusoidal current (G3-112) was the source of additional magnetic field with near 0.004 T maximal amplitude of inductance. The coil was placed near lateral surface of a rectangular specimen so that the induced magnetic field was approximately orthogonal to electric field (G5-54), produced by electrodes fasten to other (transversal) facets (Fig. 2 a). Alternative magnetic field was used to avoid negative bias of ferromagnetic elements of press. Phases of generators to electric and magnetic supply were synchronized with the help of triggering unit. The unit produced a triggering signal to start G5-54 generator when the current in magnetic coil reached the maximum. Just after the end of electric pulse of G5-54 the triggering unit allowed no new pulse during specified dead time (nearly half period of AC sinusoidal current of magnetic coil supply). So, the frequency of electric field induced in the specimen was two times less than that of magnetic field (Fig. 2 b). It should be emphasized that the direction of dynamical force and the vector of energy flow remained the same during the session with action of crossed E and B fields.

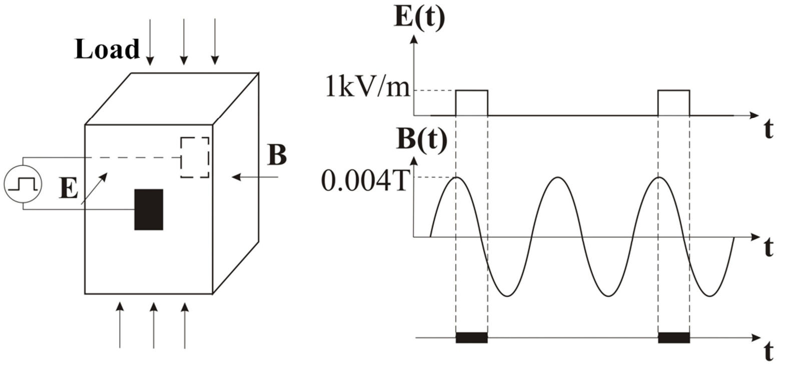

Fig.2. Experiment with loaded specimen in crossed EM field: a) the geometry: directions of main compression (vertical), electric field E, and magnetic inductance B are orthogonal, b) synchronization of periodical electrical pulses (G5-54) with AC generator supply to magnetic coil.

In addition to computation of usual AE activity (the based informative parameter) we determined the rate of accumulation of AE events of major and minor magnitudes. For this purpose we separated the flow of AE signals on 2 groups called “strong” and “weak”. AE signals with amplitudes above the given discrimination level were considered as “strong”, other signals - as “weak”. The program of numerical discriminator working with recorded waveform of AE signals was used. We prescribed the level of discriminator so that the numbers of strong and weak AEs per second (the selective activity parameters) were comparable, say the difference between their trends should be less than 50 %. As a result, we get information closely related to kinetics of structural defects of various sizes.

Results and discussion

Previous experiments performed with different kinds of rocks under creep test in presence of electromagnetic field [6, 8, 9] revealed the effect of energy release increase (relaxation). These fundamental results were obtained by means of AE activity parameter. In the experimental series held at RS RAS [10, 11] AE activity responses with time profiles as shown on Fig. 3, and with considerable increments of AE (exceeding triple level of AE root-mean-square over steady background) have occurred in 22 cases from 26 sessions. The responses have been observed when the value of main compression stress was from 0.7 to 0.95 of fracturing for given specimen. Temporary activation of AE (Fig. 3) and correspondent growth of accumulated energy release are followed by partial relaxation of specimen material. By other words, some zones of stress concentration (source sites of AEs) are to unload themselves after triggered emissions. It should be highlighted that in experiments such as described in [9] dynamical stress due to electric ponderomotive force is about 7 orders of magnitude less than the main compression stress. It is worth to remark that a delayed increment of AE activity after EPI is a realization of triggering which is quite similar to the activation of weak seismicity after powerful electric discharges supplied by geophysical MHD generators [18]. The similarity of emission responses on various scales of geological medium is to denote that electrostimulation effect is definitely fundamental for overstress unloading in Earth Crust and adaptation of its material to stressed-strained state. Potentially, this effect could allow the controlled release of overstress.

Fig. 3 a demonstrates an example of the effect of AE activity stimulation by powerful electric impacts produced by capacitor discharges, Fig. 3 b by periodical electrical pulses by G5-54 generator and Fig. 3 c by combined action of crossed electric and magnetic fields. As a whole, these examples of various AE responses are an expression of general features of electromagnetic effect in rocks.

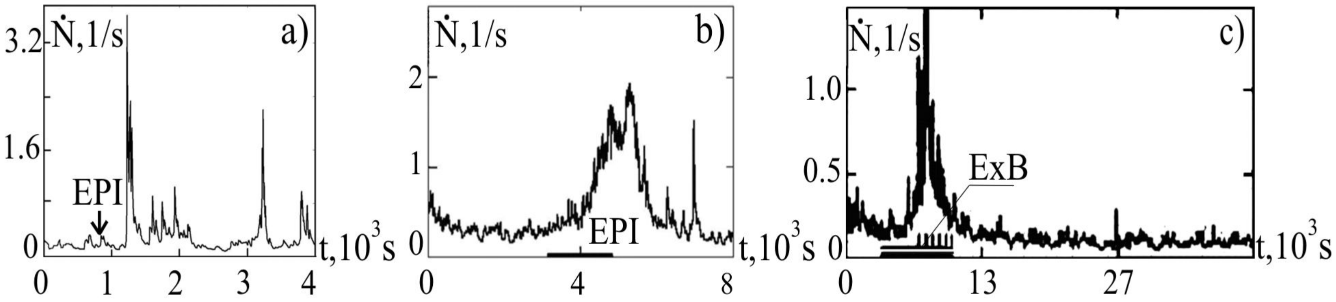

Fig.3. Plots of AE activity ($\dot{N}$), versus time (t): a) gabbro, action of capacitor discharges; b) gabbro, periodical pulses of generator G5-54; c) granite Westerly, session with crossed E × B fields power on.

To get some information about evolution of energy release (peculiar relaxation) we considered separately the flow of AE signals of major and minor magnitude and calculated the selective AE activity for each group. The data obtained on granodiorite specimen under action of EM field have been processed, the results are shown on Fig. 4 a - c. According to our previous investigations electromagnetic pulses are working effectively to stimulate AE when the normalized load is high enough, typically exceeding the level 0.8 of fracturing value. So, we focused our attention on three sessions with EPI during which the values of compressive load were equal 179, 188, and 198 MPa. These compression stresses were near critical, because the ratios of these loads to fracturing value for given specimen (K_{NL}) were as follows 0.86; 0.91; 0.95. The periods of electric pulses supply lasted an hour (denoted by black bars on Fig. 4). A square waveform generator G5-54 was used. Each case of Fig. 4 demonstrates two temporal dependencies, and the dark line denotes the activity of strong AE signals (of major magnitude) and the grey line the activity of weak AEs (minor magnitude).

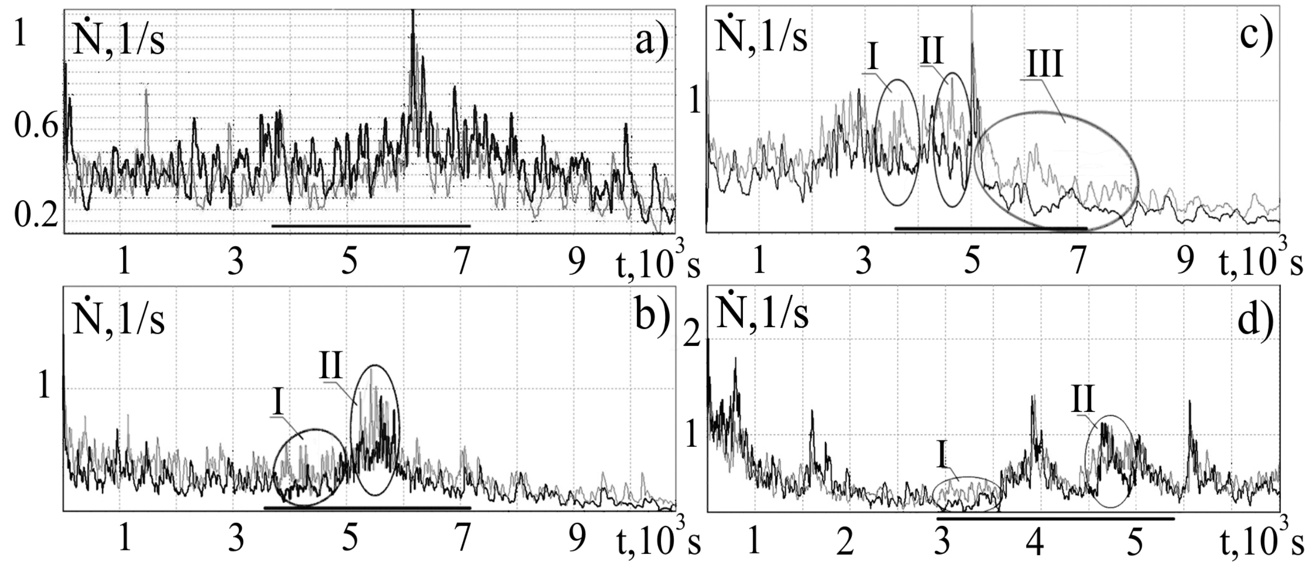

Fig. 4. Temporal plots of $\dot{N}$ of granodiorite specimen at three fixed loads (a - $K_{NL} = 0.86$; b – 0.91; c – 0.95); d) the same plot of AE activity of gabbro ($K_{NL} = 0.87$).

In the first case (Fig. 4 a) the temporal dependencies of activity of major and minor AEs are practically identical, and electromagnetic action does not affect the similarity of trends of curves. But this is not the case when the main load has increased and the background level of AE activity becomes higher (Fig. 4 b). One can see that some growth of minor AEs simultaneous with slight fall of major ones occur just in the beginning of square waveform electric pulses supply (interval I on Fig.4b). Meanwhile, the response of total AE activity arrives later than the dissimilar variation in interval I. Dissimilar variations of activity of major and minor AEs have been observed also in interval II, simultaneously with the maximal increment of total AE activity. The distinction of curves is more apparent compared to that in interval I. This notes that under considered load of 180 MPa ($K_{NL} = 0.91$) *AE signals of minor magnitude provide the most part of total activation.*

During the last session for given specimen a spontaneous spike of AE activity has occurred before start of EPI. This fluctuation is to mitigate AE increase stimulated by electric pulses, since a number of metastable zones (ready to emit acoustic energy while weak actions) is less after the spike. It is of interest that *only marginal difference between trends of minor and major AE plots has been observed in the period of spontaneous activation.* In contrast to the “prehistory” up to 3600 s, three episodes of obviously dissimilar or even antipodal variations of both selective AE plots take place during action of electric pulses. Intervals I- III on Fig.4c denote these episodes in the period of EPI. The first dissimilar variation has arisen just after the start of electric action, similarly to that at previous stage of loading (case of Fig. 4 b).

Beside data on granodiorite specimen we have processed primarily data and analyzed the results of the experiment with other rock specimen, namely gabbro. AE measurements have been performed during a session when the compressive load is 0.87 of maximal for given specimen. G5-54 generator has been used as a source of EPI, the period of electric action is shown by a bar on Fig. 4 d (in the same manner as I the cases a - c). One can see on Fig. 4 d that AE activity response consists of two successive spikes. Before external action both activity plots: for strong and weak AE signals temporal dependencies, have practically the same trends. Fluctuations of activity, which are correspondent to near random character of AE sources occurrence, give no statistically valid deviation on averaged plot. But during the session with electric pulses, two intervals are to attract attention, when the growth of weak events flow takes place while steady or even decreasing flow of strong events. The first interval is in the beginning of period of EPI, actually it coincides with the transition period before the front of activation. The second interval of dissimilar variation is correspondent to a burst of activity. The length of these two intervals is about 850 s, or near one quarter of EPI period and less than 0.1 of total time of the session.

The results of analysis of selective activity of AE have demonstrated that the concept of self-similarity (proportional each to other change in accumulation of major and minor defects) is fulfilled during the most time, but in some episodes the deviations like dissimilar mode of responses may take place, due to action of EM field. Such results are typical for sub-critical loads. They probably look like peculiar relaxation after EPI in superimposed on rock materials in stressed-strained state, when the compressive load is close to fracture.

Comparison of responses to trial load and electric pulses. Some extra experiments were performed as a topical development of above noted studies. The aim was to compare the characteristics of AE responses (spikes or raised plateau intervals at temporal plots of AE activity) due to electric pulses with those caused by trial relatively small increments of compression load. Specimens of both kinds of material: semi-brittle rocks (granites) and pseudo plastic ones (rock salt) were used. The experimental technique for specimens test by compression load and electric pulses and the measuring system were the same as in previous experiments [9 - 11]. The only modification involved a new modulus for AE signals filtering, which allowed continuous measurements of AE even during trial load increments. The Fig. 5 a demonstrated the results of measurements of AE from a granite specimen (Sary-Jaz deposit, Kyrgyzstan). In the given measuring session with the specimen under compression stress of 100 MPA value (near 0.85 of fracturing) the level of AE activity was steady (near 4 events per second). In the middle of the session the load was increased up to new steady value 107 MPA. The correspondent increment of axial strain was about $3.5 \cdot 10^{-4}$, and the trial energy input (work of deformation during trial loading) was approximately equal to 5 J. This extra loading resulted in sharp rise of AE activity (Fig. 5 a) which was followed by drops of AE events flow similarly to Omori law [19]. The relaxation lasted near 180 s. During this period approximately 4100 AE events were recorded. One can evaluate the number of stimulated events by subtracting the contribution of background activity (defined in prehistory and extrapolated to activation interval) from total AE accumulation. So, approximately 3400 events seemed to be triggered by additional compressive load.

Thereafter, with some time lag the source of electric pulses (square waveform generator) was powered on. The specimen was biased by unipolar pulses; the amplitude of electric strength was about 400 V/m, the frequency was equal 50 kHz. The amount of energy absorbed by specimen during electric field action may be roughly estimated as $2 \cdot 10^{-2}$ J (only the order of magnitude is of significance). This evaluation is based on the parameters of electric pulses, geometry of supplying electrodes and the value of dielectric loss tangent for the material of tested specimen. The response to electric pulses (EPI case on Fig. 5 a) exceeded that in “pure mechanic” case (TL-spike on Fig. 5 a) by the duration and magnitude of AE activity increment. The number of events triggered in 300 s period of electric biasing was estimated as to be near 7100 ± 50 (the accuracy was limited by near 0.5 s uncertainty in time of electric source start). It should be noted that 5700 ± 50 electrically stimulated events occurred in first 180 s of biasing, this is 1.7 times more than under previous “TL-activation”. The ratio determined for a granitic specimen exceeded unity, meanwhile energy supplied externally in the first case (trial loading) was much more than in the second.

Similar results were obtained on specimen of pseudo plastic material (rock-salt). The specimen of such creeping material was tested on lever-gravitational loading machine for which no specimen decompression can take place due to its shortening (in contrast to spring press). Fig. 5 b represented the temporal dependence of AE activity of rock salt specimen under uniaxial compression stress of 30 MPa value (0.85 of fracture by cracking). The background activity of AE was about 4 events per second (close to the case of granitic specimen), but with slight decreasing trend. Again, trial loading was undertaken firstly in the measuring session. The increment of stress was about 0.5 MPa, the correspondent change in axial strain was of order of $(1 - 2) \cdot 10^{-4}$. The energy input to the specimen may be estimated as a product of mean acting load by specimen shortening caused by stress increment. The value of energy input was between 1 to 2 J. The trial loading caused the response of AE activity of 4700 s duration. Then AE activity relaxed to a new steady level. The number of triggered events during the spike interval was 5050 ± 50.

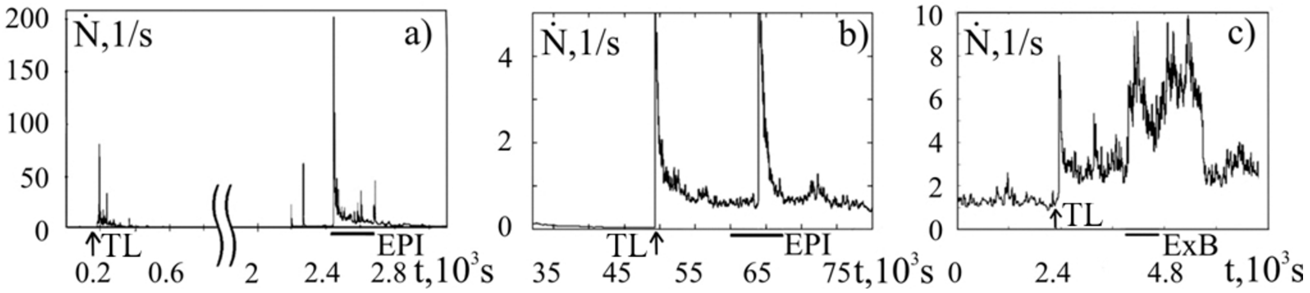

Fig.5. Plots of AE activity ($\dot{N}$), versus time (t): a)granite; b)rock salt; c)granite, anywhere K_{NL} =0, 87

The second abrupt activation of AE (see plot on Fig.5b) was stimulated by electric pulses produced by the same square waveform generator. This time the amplitude of electric strength was about 10^3 V/m, the frequency – 2.2 kHz. The amount of absorbed electric energy was nearly 0.05 J. The spike of AE activity (the response to electric pulses, by other words) became with rather long delay after start (near 4000 s). The duration of the second spike on Fig.5b was 3300 s. In the spike interval nearly 4100 AE events were recorded, and 2500 of them were above accumulation due to part of "unchanged", background level activity and may be considered as stimulated. Meanwhile, in the case of response to trial loading more than 4200 events occurred in first 3300 s after TL-moment (Fig. 5 b). We regarded these events as triggered because the level of AE activity was too low before load increment (so, it cannot explain the accumulation of 4200 events during 3300 s interval). A ratio of number of AE events induced in the case of EPI (second spike on the Fig. 5 b) to similar number of those in the case of first spike can describe a potential of electric pulses to activate AE. For the rock salt specimen this ratio appears to be equal 2500/4200 ≈ 0.6.

An important result was obtained on the specimen of another sort of granite than that of Fig. 5 a. The specimen was tested on lever-gravitational loading machine also as rock salt specimen. Fig. 5 c represented the temporal dependence of AE activity of granite specimen under uniaxial compression stress of 198 MPa (0.85 of level of fracture by cracking). The background activity of AE was about 1.4 events per second, but with stable trend (unlike to previous experiments). Stability of background values (values of AE activity before any external action) was estimated as constant level with error of 5 - 8 % due to a considerable fluctuation which occurred before trial loading, or before interval of E × B pulses (as evident from Fig. 5 c). Following our overall technique we undertook the trial loading at first. The increment of stress was about 0.4 MPa, the correspondent change in axial strain was of order of 10^{-4}, and the energy input to specimen was about 0.5 J (estimated by work done, in the same manner as before).

The trial loading caused the response of AE activity of 120 s duration. Then AE activity relaxed to a new steady level of 3 events per second. The number of triggered events during the spike interval was 2790 ± 20. Activation of AE (see Fig. 5 c) due to the external action produced by crossed E × B field began just after the start of the action. Only one minute delay was required to achieve the maximal level of AE response in this case. This time the amplitude of electric strength was about 400 V/m, the frequency – 3 kHz. The pulse frequency produced by the generator G3-112 (magnetic field) was 6 kHz. The amount of absorbed energy due to power influx of crossed E × B fields was nearly 0.1 J (this estimation based on values of the Pointing vector and total duration of all E × B pulses, sketched on Fig. 2). The duration of the AE response (Fig. 5 c) is 1765 s. During the response nearly 10800 AE events were recorded; and 5990 of them were triggered by external fields. Meanwhile, the response to trial loading (first spike on the Fig. 5 c) involved more than 2790 induced AE events. Given estimate resulted from the difference between actual accumulation of AEs and extrapolation of previous level of AE activity to period after TL-moment. For the same length of observation (1765 s) the ratio of electric- to trial loading stimulation was ~ 2, which was similar to the data obtained from the previous experiment with granite sample. Such value of the ratio allowed to remark speculatively that the stimulation of AE source sites by electromagnetic pulses may be effective so as that by increment of mechanical load.

To summarize and compare results for semi-brittle and pseudo plastic specimens we calculated the ratio of energy input to relevant number of triggered events. The values of energy per unit triggering (EUT) were placed in Table 1, for sessions with trial loadings and electric actions. In the case of trial loadings the specific increment of strain (per triggered event) was calculated as well.

Table 1. Absolute and specific values of parameters describing triggerability of additional trial loading (TL), external power impacts (EPI) and action of crossed electric and magnetic fields (E × B).

Specimen	Action	Strain increment	Number of triggered events	Specific increment of strain	Energy input, [J]	Number of triggered events	Value of EUT, [J]
Granite #1	TL	$3.5\cdot10^{-4}$	3400	10^{-7}	5	3400	$1.5\cdot10^{-3}$
	EPI	Not applicable			0.02	7100	$3\cdot10^{-6}$
Rock salt	TL	$(1\text{-}2)\cdot10^{-4}$	5050	$(2\text{-}4)\cdot10^{-8}$	1-2	5050	$(1\text{-}2)\cdot10^{-}$
	EPI	Not applicable			0.05	2500	$2\cdot10^{-5}$
Granite #2	TL	10^{-4}	2790	$3.5\cdot10^{-8}$	2.5	2790	10^{-3}
	E×B	Not applicable			0.1	5990	$2\cdot10^{-5}$

Table 1 denotes a great difference in values of EUT for electrically triggered AEs of granitic and rock salt specimens (more than 3 orders of magnitude). Regarding the activations due to trial loadings, the values of specific strain increment and EUT for these two specimens differ from each other less than an order. It is a surprising result that from the viewpoint of AE (microcracks growth) triggering the distinction of rheological properties of semi-brittle granitic specimen and pseudo plastic rock salt one plays no serious role. AE stimulation by electric pulses of generator G5-54 appears to be the most effective for granitic specimen, since in this case the energy price for one extra AE event is minimal as compared to trial loading stimulation and in comparison with rock salt specimen under electric impacts as well. However, the most effective way to trigger the energy release is the combined action of magnetic field with synchronized periodical electrical pulses. This crossed E × B fields action give rise to AE activation with the minimal delay, and the accumulation of the most number of triggered events.

Summary

The experimental results have demonstrated that the effect of EM fields applied externally is of potential to modify the process of defects accumulation in rocks under near critical loading conditions. The prevalent reaction of rocks materials to electromagnetic pulses is the temporary increase of microcracking rate. During the induced activation the proportion of major and minor sizes defects is without change, in accordance with observed self similar activation of AE. Stimulated release of extra energy is seemingly followed by relaxation of stress distribution nonheterogeneity. The dissimilar AE activation with preferred formation and growth of defects of minor sizes can be triggered under specific conditions, in particular, on compressive loads of value 0.9 – 0.95 of fracture, providing the microcracking process (average AE activity) is still steady. This is a non-trivial resource for relaxation and inelastic strengthening.

The analysis of energy per unit triggering has proved that electromagnetic pulses (impacts of crossed electric and magnetic field and other EPI with optimized parameters) may stimulate AE similarly to small (few percents) increment of load. A suggestion that EM pulses affect the softened domains on the background of quasi uniform distributed mechanical stress could explain the low value of EUT in comparison with trial loading.

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